SOIL PIPING
IN SOUTHEASTERN ARIZONA

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Destructive piping on an abandoned farm near Benson, Arizona.

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Illustrations

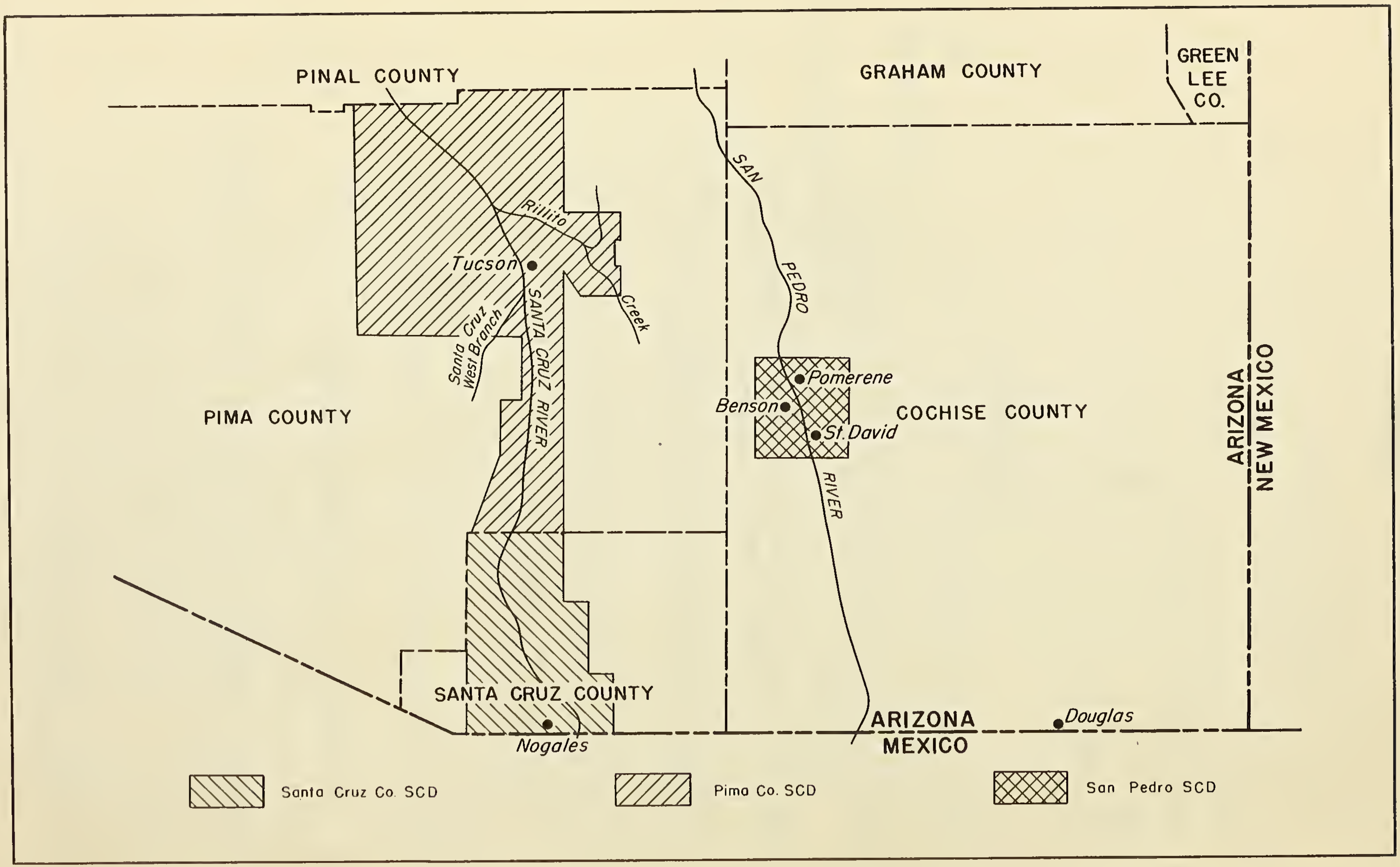

Figure 1. Sketch Map Showing Location of Counties, Soil Conservation Districts, Towns and Rivers Mentioned in the Report.

SOIL PIPING IN SOUTHEASTERN ARIZONA

Introduction

Farmers of the San Pedro, Pima County and Santa Cruz County Soil Conservation Districts often make inquiries relative to the cause and manner of handling that form of subsurface erosion known locally as "piping" or "tunneling." Many attempts to handle this peculiar erosion condition through generally approved conservation practices have proved ineffective, and numerous farmers have endeavored, some successfully, to apply their own ingenuity to the problem.

The problem of "piping" soils in this locality is an old one, but there was, at the time of this study, little information in the technical literature on the subject.

The object of this study is to obtain a better understanding of and more extensive information on the "piping" of soils. No attempt will be made to fully discuss the inherent physical and chemical characteristics of "piping" soils*, but attention will be given to those factors of soil cracking, land settling etc. which have been observed to precede or accompany pipe formation. It is hoped that these personal observations will add something to our knowledge of this form of erosion and will stimulate the development of practical and economical methods of handling this soil problem.

"Piping or Tunneling" and "Sinkholes"

"Piping or tunneling" is the descriptive name given to that form of accelerated erosion which results in subterranean voids and tunnels (see frontispiece). This type of erosion is common to highly dispersed ** alluvial soils.

"Sinkholes" result from a differential settlement of the land or from the collapsing or caving-in of subsurface tunnels and voids (Fig. 2).

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* A more complete study of the inherent factors associated with piping soils may be found in the following publication:
Fletcher, Joel and Carroll, Paul H., "Some Properties of Soils that are Subject to Piping in Southern Arizona", Soil Science Society of America Proceedings, 1948. (1)

** If a sample of very fine soil fraction is shaken in water, it passes into a state of suspension. The surface of each of the particles is the seat of a negative electrical charge. If the water is pure, no two particles come into contact because they carry like charges which repel each other. The sample is then said to be in a state of complete dispersion.

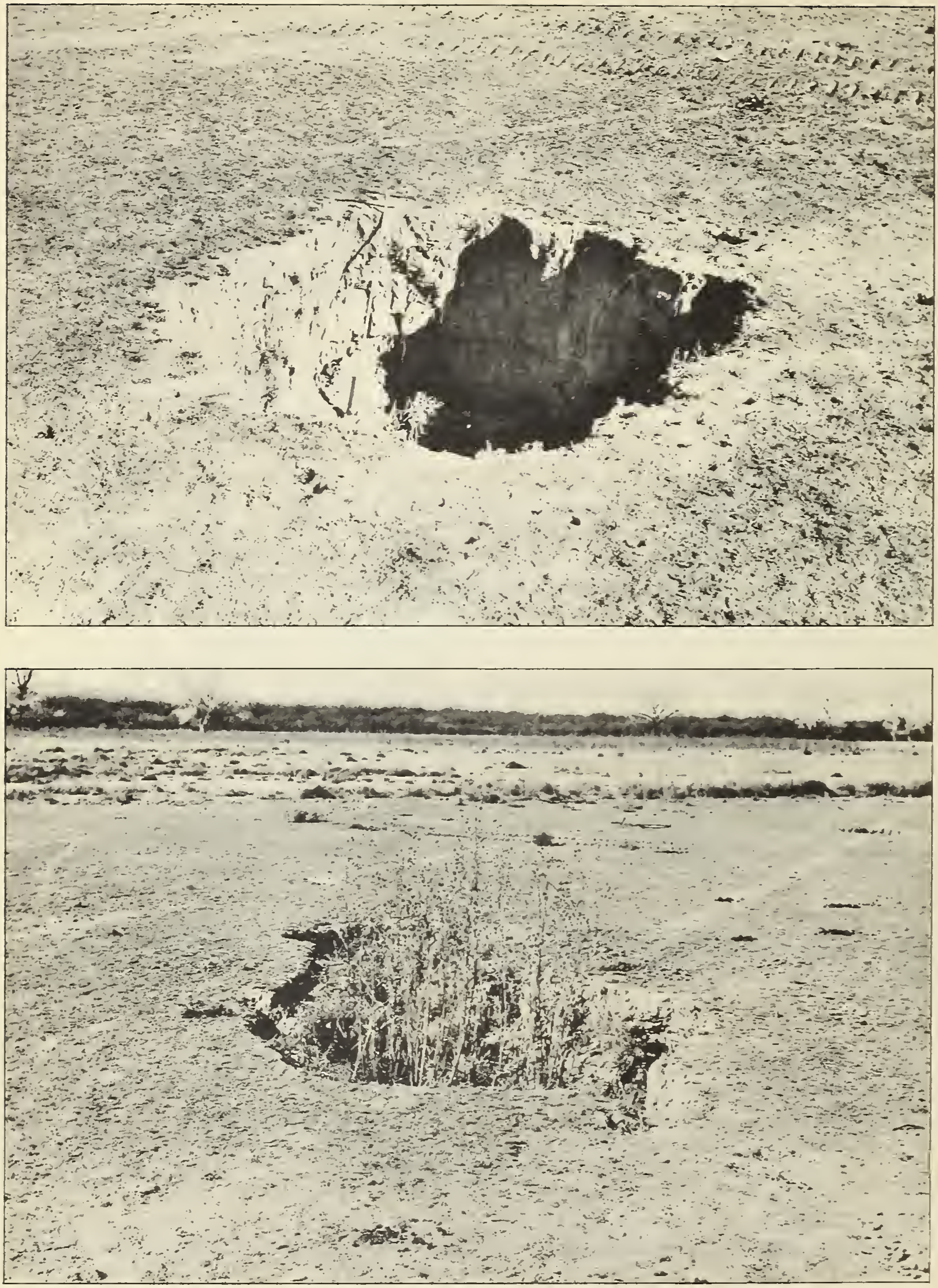

Figure 2. Sinkholes in the alluvial soil of the San Pedro River valley near Pomerene, Arizona.

Occurrence

Abundant visual evidence of the piping of soils is afforded in the alluvial deposits of the Southwest. Piping or tunneling and sinkholes have been observed in water-laid soils from New Mexico to California and from Utah to Old Mexico, but no one group has shown greater susceptibility to this form of accelerated erosion than have certain soil groups of the Santa Cruz and San Pedro River valleys.

Piping, in both early and advanced stages, has been observed in the valleys of the Tucson-Nogales and Benson areas. The Tucson-Nogales area includes the comparatively narrow alluvial valleys of the Santa Cruz River and its main tributary, Rillito Creek. Piping has also been noted in the lower courses of the nearby Pantano Wash, Canada del Oro and Aura Wash, and on the bordering narrow strips and intervening or adjacent areas of bench lands. In the Benson area, piping is limited to a part of the trough or plain of the San Pedro River.

Piping appears, in all cases, to be most pronounced in the uniformly fine-textured soils of the Gila and Pima series in the Pima and Santa Cruz County Soil Conservation Districts and in the Gila, Pima, Riggs, Curtis and San Pedro series* in the San Pedro Soil Conservation District. The eroded areas are usually limited to narrow strips adjacent to the stream channels in the valley part of the area, but excellent evidences of piping may be observed in places in old alluvial deposits as far as one mile from the present channel. In all instances, the soils are derived from water-laid deposits which have been altered through weathering and reworking by surface waters since deposition.

Formation

Piping, like other forms of accelerated erosion, may depend to a marked degree on the amount and intensity of rainfall, the slope of the land and its general topography, the size and shape of the watershed, the presence of channels in which water becomes concentrated, the type and amount of vegetative cover and the nature of the soil and subsoil. But piping, unlike other types of erosion, results in removal of the subsoil and substratum without necessarily eroding the surface soil. The surface soil in piping areas is generally composed of soil similar in texture to the immediate

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* Taken from U.S.D.A. survey reports of the Benson (2), Nogales (3), and Tucson (4) areas, Arizona.

subsurface layers. However, it is slightly higher in humus and mycelia which assist in stabilizing the surface against erosion. During the process of subsurface erosion, the more erodible subsoil and substratum are removed in water suspension; whereas, the more stable, less erodible surface soil remains firmly in place until it becomes undermined and can no longer support its own weight.

The formation of huge subterranean tunnels with unsupported roofs is possible only in soils with at least a trace of cohesion. The greater the cohesion, the wider are the spaces that can be bridged by the soil. In a general way, the cohesion of soils increases with decreasing grain size, and the danger of piping due to subsurface erosion increases with decreasing grain size.

Before piping can occur in any soil there must be provided an avenue of escape for the migrating soil particles. In some areas the soil is underlain at variable depths by highly porous, sandy or gravelly strata that permit a downward movement of the transported soil. Other piping areas are adjacent to deeply cut stream beds or gullies which permit a lateral movement and escape of the suspended soil particles. Soils known to be highly susceptible to piping may remain comparatively undisturbed for years if they are not provided with these paths of removal.

Though we are aware that piping in soils is made possible by the existence of escape avenues for the dispersed soil, we are not always certain of the manner in which these exits are formed. Soil conditions conducive to piping may result from one or more of several factors.

The type of piping with which we are most familiar begins with the burrowing action of gophers and other animals. Animal holes and burrows provide paths or openings through heavier-textured surface and subsoils to underlying strata of sand or gravel or extend laterally to adjacent streambeds or gullies (Fig. 3).

An excellent example of piping in which animal burrows have provided escape avenues into underlying gravel beds is afforded by soils of the old Santa Cruz West Branch near Tucson, Arizona (Fig. 4). These soils are made up of clay loams overlying thin strata of gravelly-sand. The formation of pipes in this area is unique among piping soils in that each time a pipe or tunnel reaches a certain stage in the erosion cycle, it tends to seal over and the erosion is brought to a halt. Actual piping begins when irrigation tailwater or overflow resulting from rainfall inundates the piping area, flows into the animal holes and drops rapidly into the sandy and gravelly substratum, taking with it considerable amounts of dispersed soil material. Due to the thinness of the gravelly-sandy layer, the amount of soil material it will accommodate is limited in amount. As soon as the porous layer is filled it will permit no further

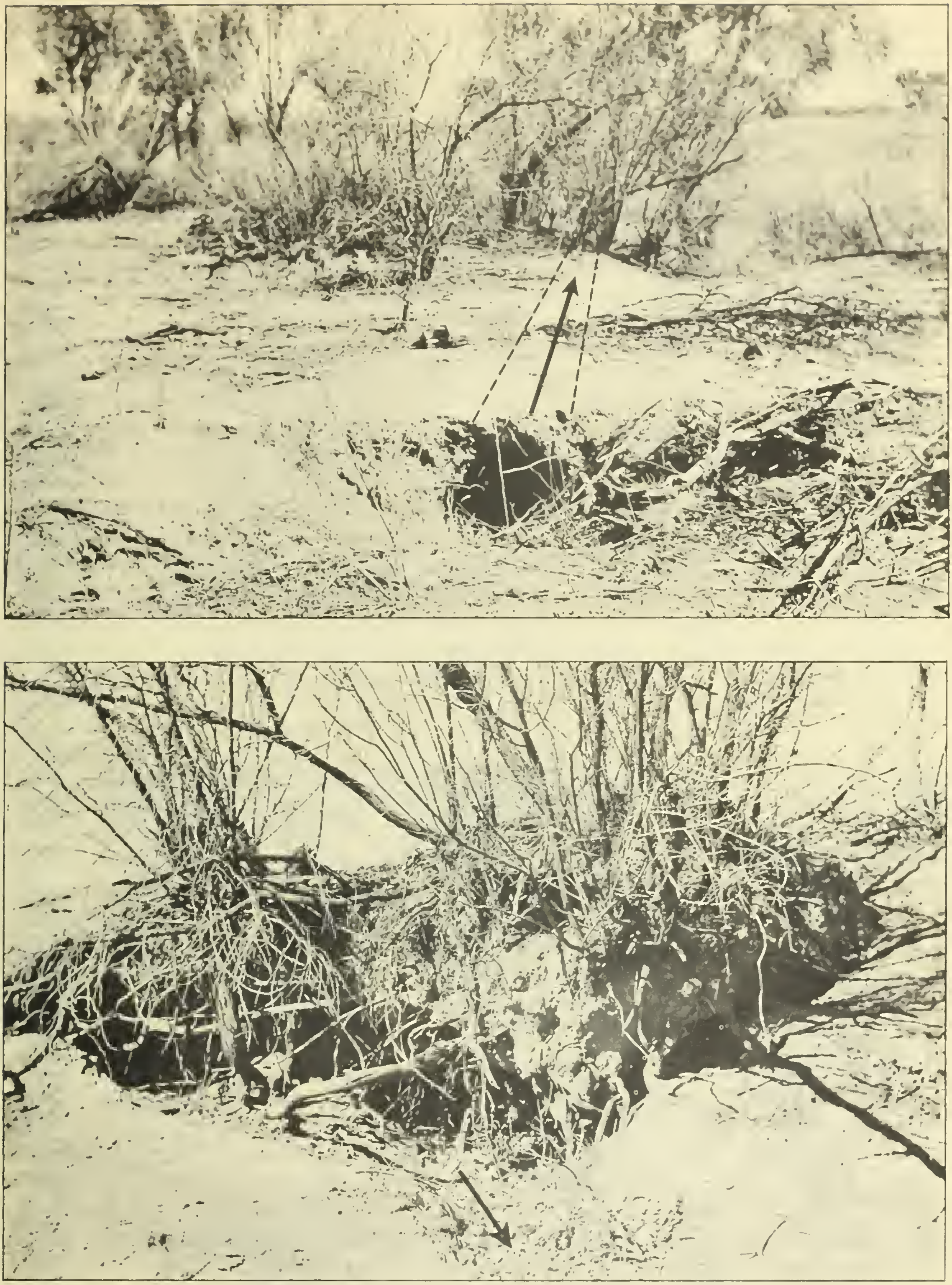
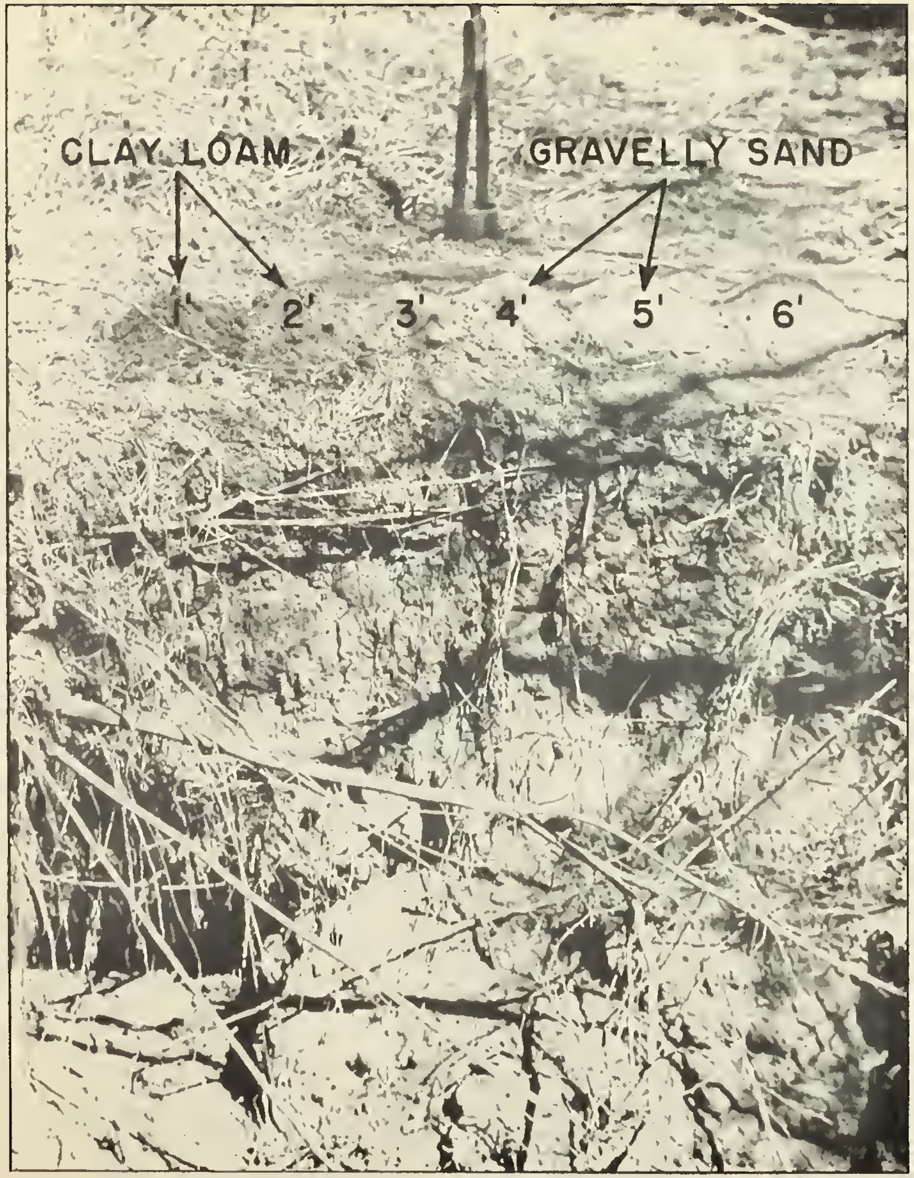


Figure 3. Entrance and exit of a pipe formed by the erosive action of irrigation waste-water flowing into an animal burrow.



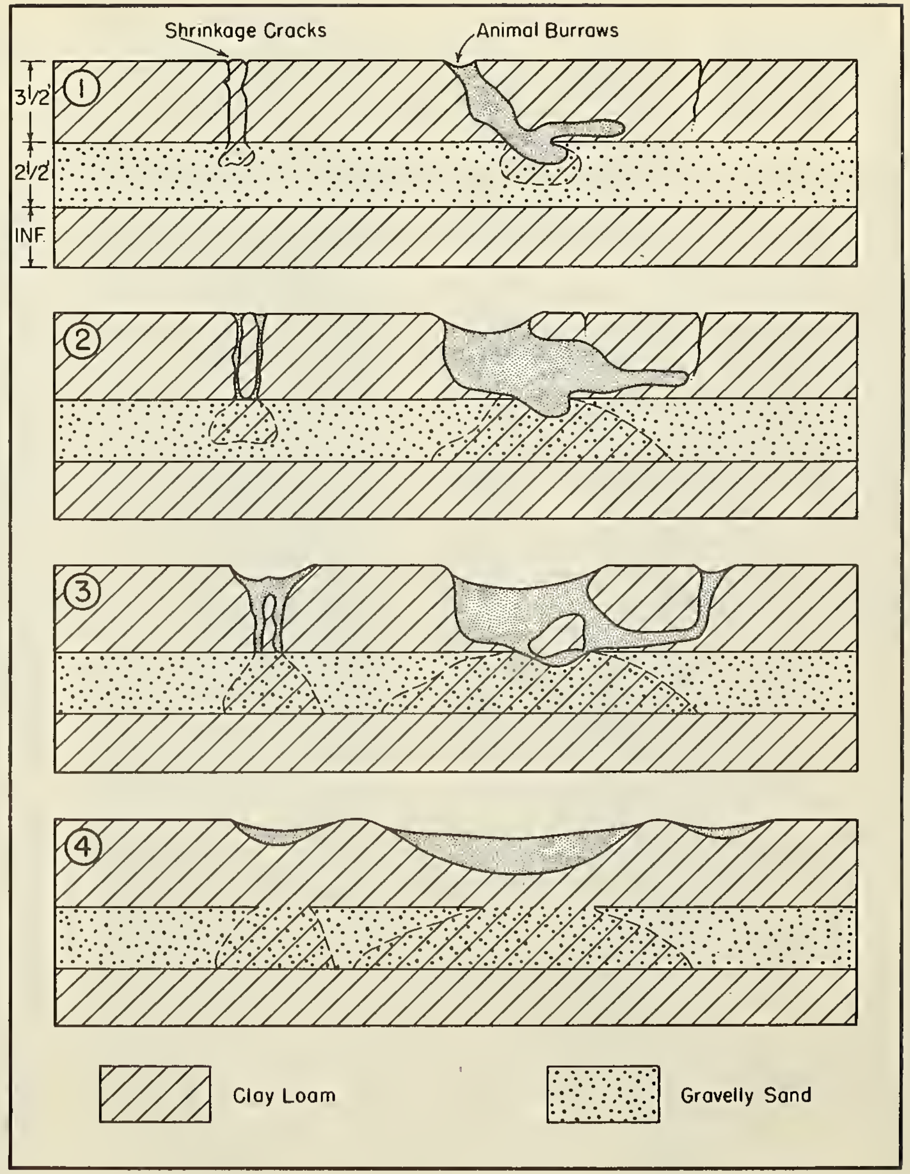


Figure 4. Soil piping in the flood plain area of the old Santa Cruz West Branch near Tucson, Arizona. Schematic drawing indicates how pipes complete an erosion cycle.

downward movement of the soil; thus, the piping is brought to a halt. Additional tailwater and rainfall will succeed only in sloughing off the walls of the pipe and creating a shallow depression in the land surface.

Another and more destructive type of piping resulting from animal holes may be observed along the high banks of the San Pedro River near Benson, Arizona (Fig. 5). Here, large areas of farms have been laid waste by piping through holes first dug by gophers. It has been observed throughout this area that where the most destructive piping occurs, channeling or impounding of surface water has been responsible for the greatly accelerated erosion. Ditches, furrows, dikes, etc. act as funnels to direct surface water into exposed gopher holes. The highly dispersed subsoil, taken into suspension by the free flowing water, is transported through the equally erodible substratum, through an outlet in the nearby embankment, and, finally, into the river. Soon the small gopher holes are converted into huge pipes or tunnels. Other gopher holes erode out to connect with the main tunnel (Fig. 6). With an increase in subsoil and substratum aeration caused by the holes and tunnels, there is a corresponding increase in the amount of shrinkage cracks in the soil profile and, subsequently, an increase in the amount of surface exposed to further water erosion.

In some areas the growth of alfalfa is thought to initiate piping and sinkholes. Growing alfalfa and other deep-rooted legumes for longer than three years has been said by local farmers to permit a too-rapid percolation of water. Decayed roots and root casts of deep-rooted plants provide paths whereby water and a suspension of finely divided soil may move downward or outward to an exit. Unless irrigated regularly, alfalfa may remove much of the moisture from the soil, and, if the soil is heavy in texture, large and extensive cracks are likely to occur (Figs. 7 & 8). As the shrinkage cracks are formed air is permitted to go deep into the subsoil and substratum and enhance still further drying and cracking of the deeper layers. The cracks in clay substrata are often sufficiently large and numerous in themselves to contain large amounts of washed in surface soil or subsoil, but if the cracks extend into underlying gravel beds or branch out laterally to gully or river banks, the amount of soil removed in increased manyfold.

Piping and sinkhole formation following a lowered water table has been observed in the alluvial soils of the Pomerene and St. David areas near Benson, Arizona. In earlier days before the lowering of the San Pedro River channel, the soils of the Pomerene and St. David vicinities had comparatively shallow water tables, and drainage of these areas was rather poor. At this time there was little or no damage to farms from piping or sinkholes. But within recent years an erosion cycle has commenced in which the channels of the San Pedro River and its tributaries have been lowered deeply into the valley alluvium. The lowering of the river channel has resulted in a

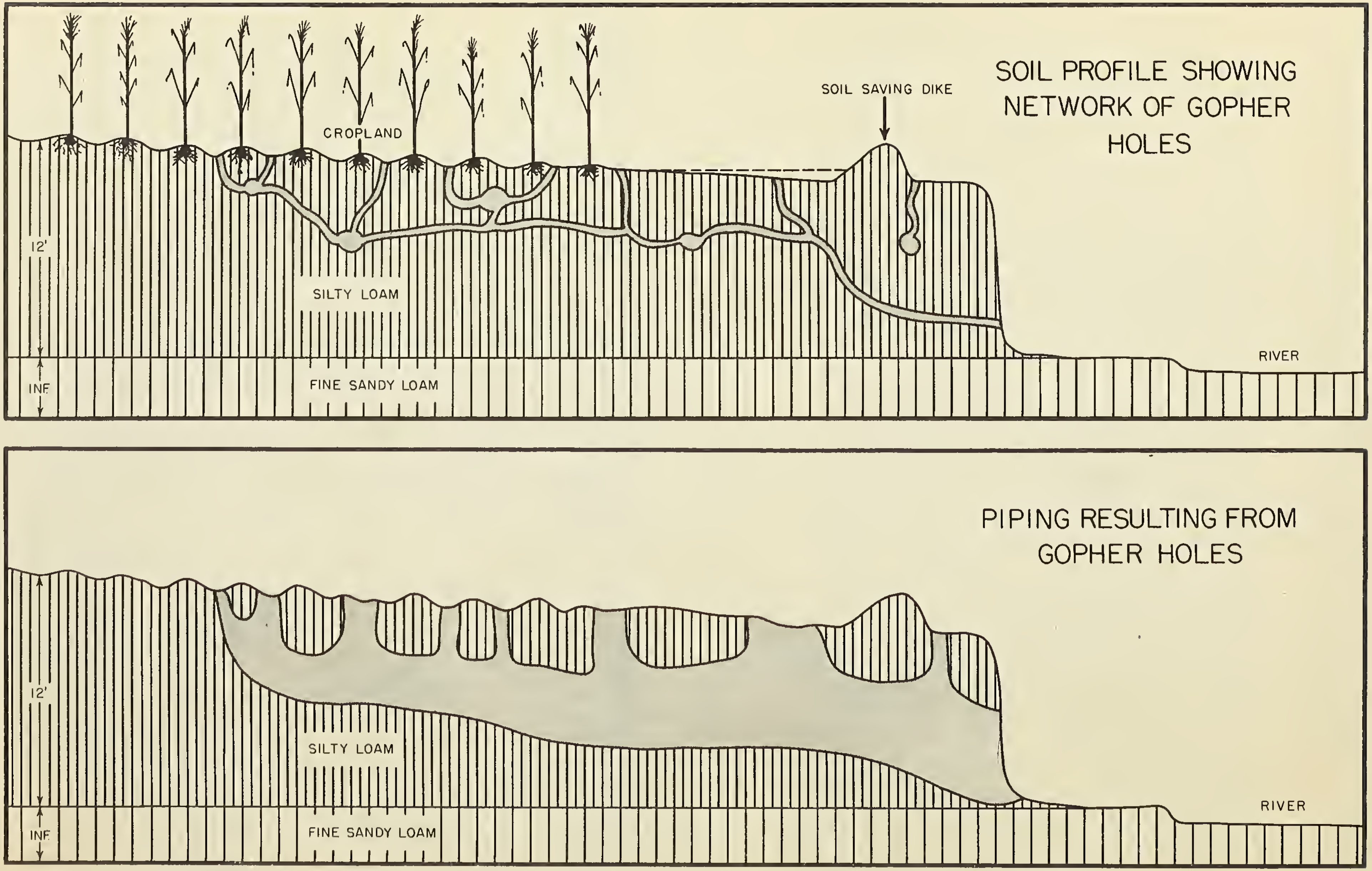


Figure 5. Schematic drawing of tunnel formation near the town of Benson, Arizona. See Frontispiece.

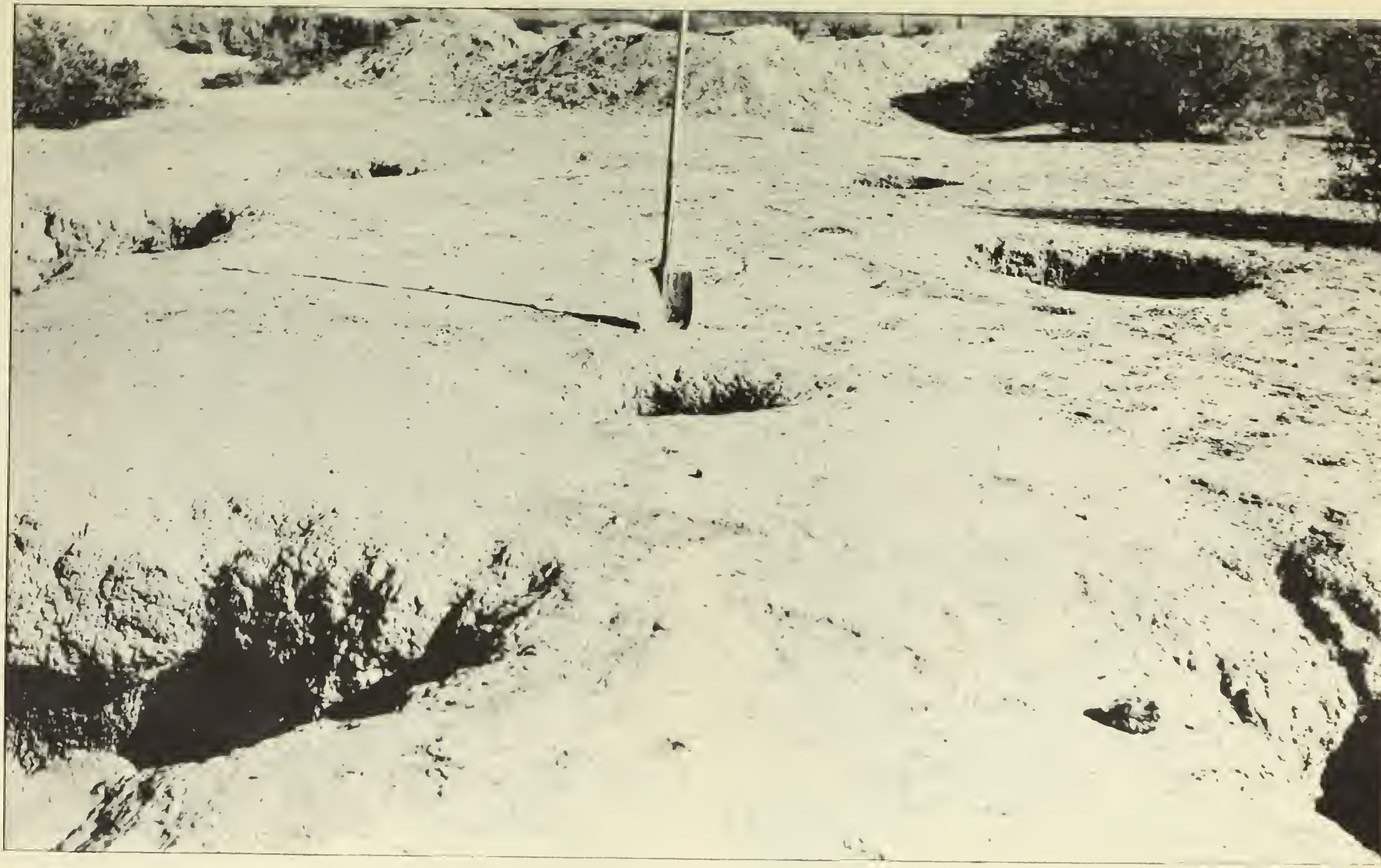


Figure 6. Subsurface erosion resulting from gopher holes. The above pipes connect with a near-by tunnel which empties into a river. See figure 5.

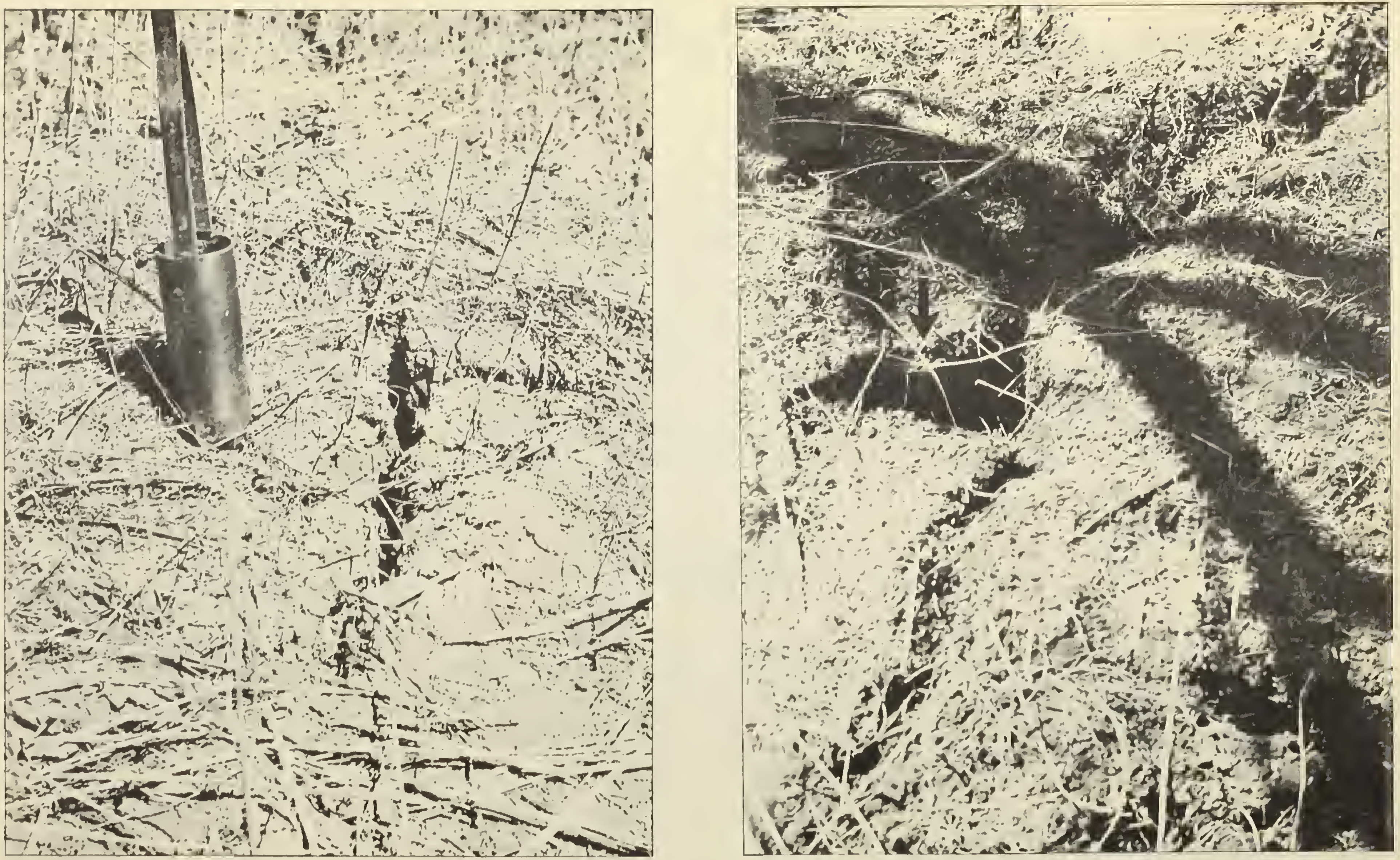


Figure 7. Deep shrinkage cracks in a heavy textured piping soil. Note in the picture to the right that the crack has begun to pipe.

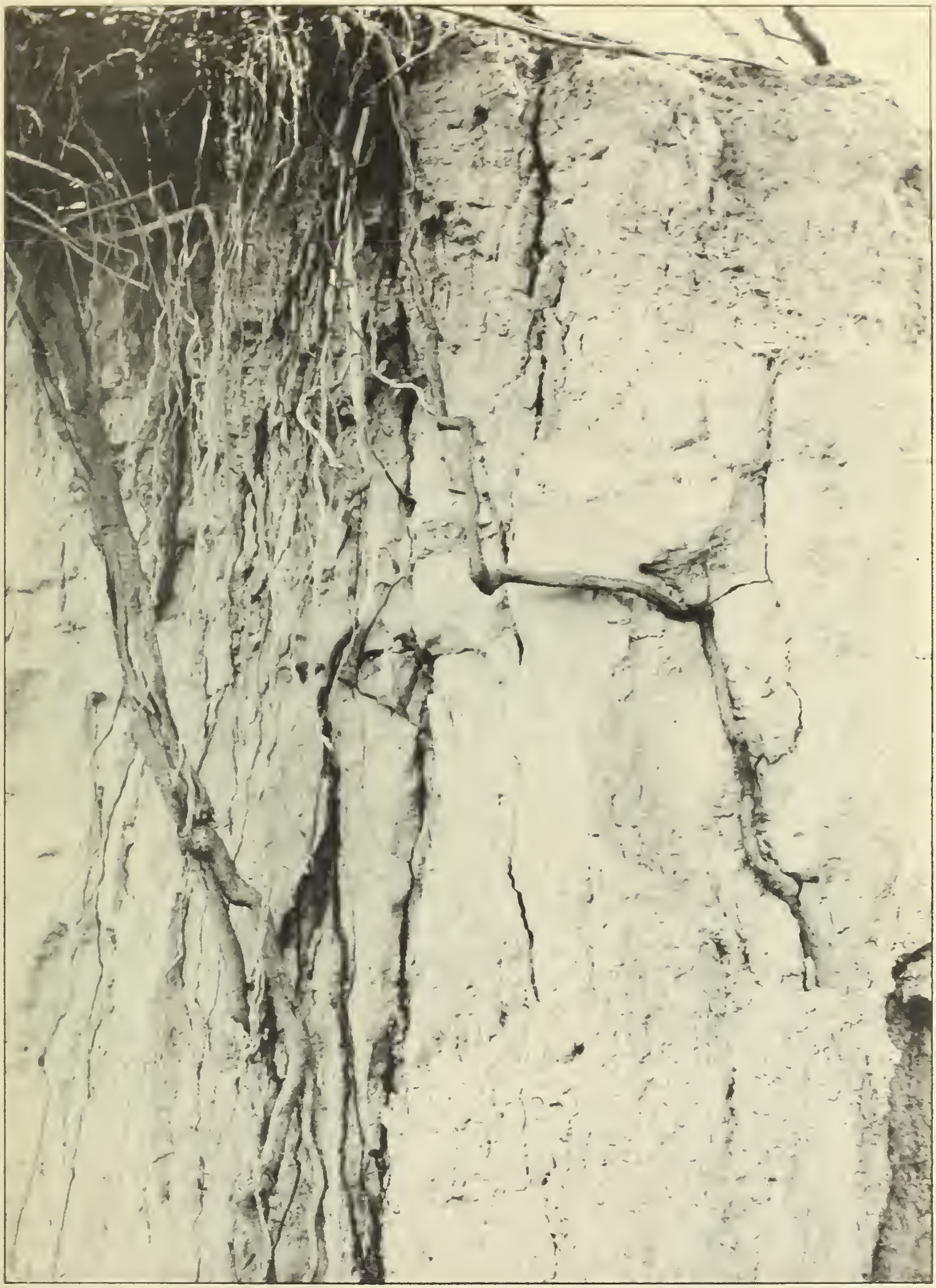


Figure 8. Profile of a heavy textured piping soil. Note the network of deep shrinkage cracks.

simultaneous lowering of the local water table, and, in those areas underlain by thick strata of sand and gravel, piping and sinkholes have become increasingly evident. With the lowering of the water table there has been a resultant differential settling of the upper soil layers coincident with the formation of deep cracks through the soil profile (Fig. 9). By lowering of the water table the effective load on the lower soil layers is increased by an amount equal to the difference between the drained weight (solid and soil moisture combined) and the submerged weight of the entire mass of soil located between the original and the lowered water table.

The increase of the effective over-burden pressure produces a settlement of the soil layers. The amount of the settlement depends on the compressibility of the lower layers; the looser the soil material in the deeper substratum, the greater is the settlement.* Often the differential settlement of the ground is, in itself, sufficient to produce sinkholes, but very frequently the settlement simply creates deep cracks which extend from the soil surface down through the soil profile into a sandy or gravelly substratum (Figs. 10 & 11). Flooding of these areas permits water to flow into the cracks and initiate piping.

Farmers living near the towns of Pomerene and St. David give added substance to this theory by their statements that they have observed, in recent years, occasional cracks over their farms that measured from two inches to six feet in width and from five to five hundred feet in length. These fissures are referred to as "earthquake cracks" because of the earth tremors that often accompany their formation. These fissures are not common to soils that are cracking as a result of drying out alone. Such a condition accounts for the chain-like formation of pipes which have been observed on many farms near the towns of Pomerene and St. David (Fig. 10).

It has been suggested that much of the piping along the San Pedro and Santa Cruz Rivers may be attributed to the erodibility of the more or less uniformly-textured, permeable soils which overlie impervious strata of denser soil materials. The downward movement of gravitational water is halted by the impermeable layer and a super-saturated soil is created. The free or gravitational water which can no longer move downward tends to flow laterally until it reaches an exit in a river or gully bank. The free water, under slight pressure, seeps from the embankment, carrying with it small particles in suspension. Soon, the soil begins to slough away, and a pipe is formed. Over a period of years, the hole or pipe may migrate back through the soil

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* Terzaghi, Karl and Peck, Ralph B., "Settlement Due to Lowering the Water Table", Soil Mechanics in Engineering Practice, p. 524, John Wiley and Sons, N. Y. 1948. (5)

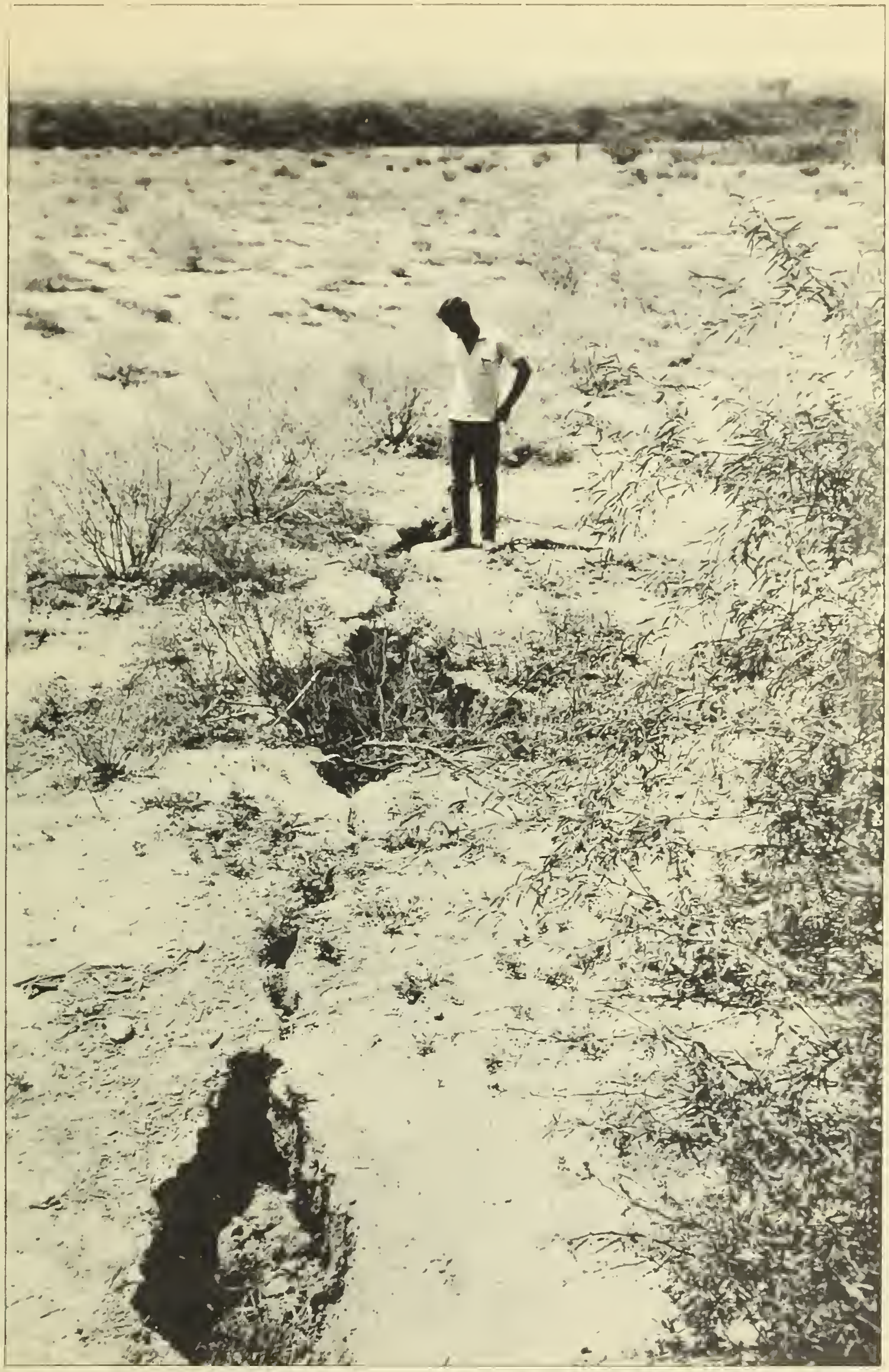

Figure 9. "Earthquake Crack" near St. David, Arizona. Crack has resulted from land settling. See Figure 10.

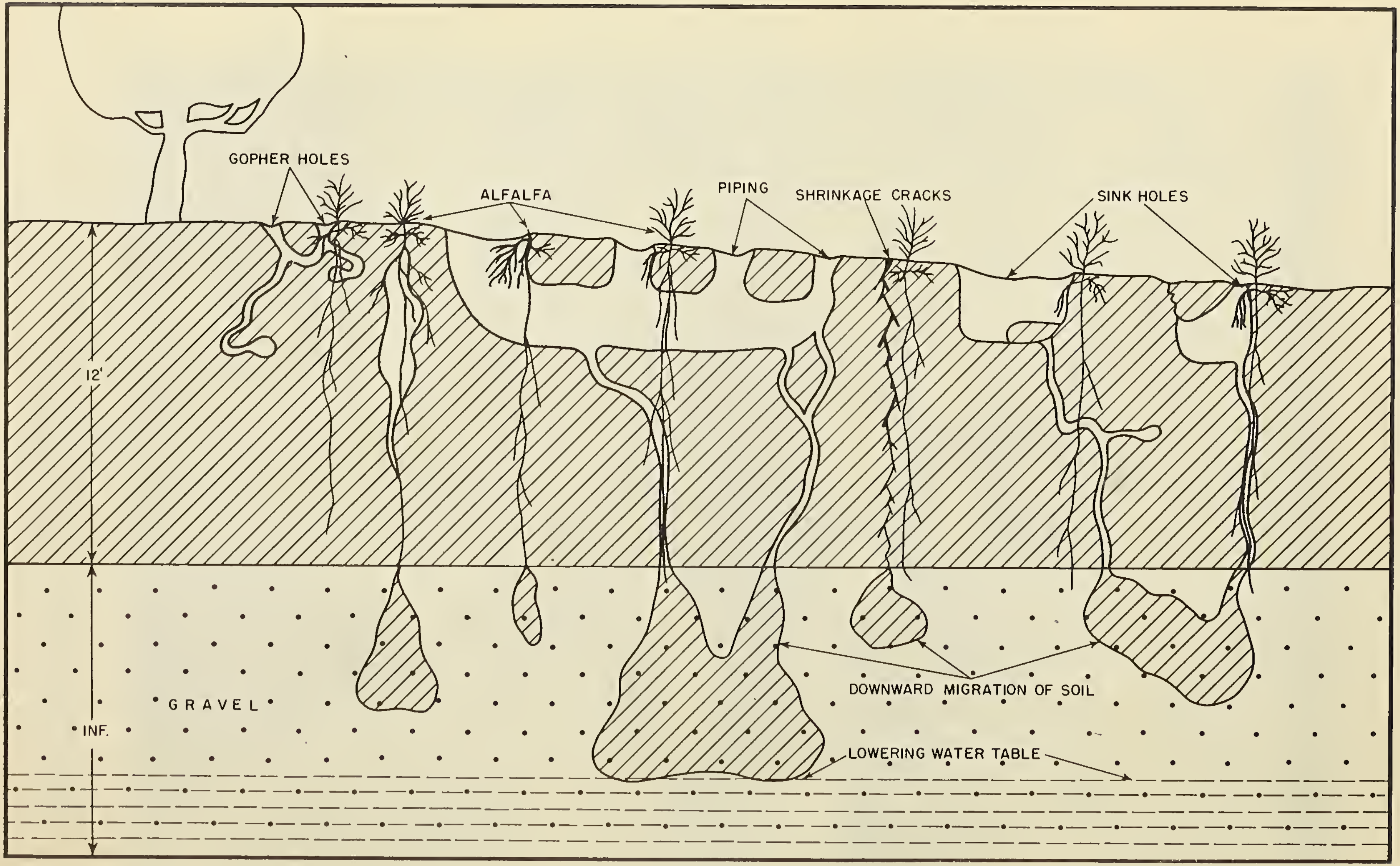

Figure 10. Schematic drawing of piping and sinkhole formation following a lowered water table. See figures 9 and 11.

Figure 11. Soil piping resulting from land settling. The bottom picture shows a chain-like formation of sinkholes which have resulted from land settling cracks.

for hundreds of feet. The clay pan beneath and the more slowly erodible surface soil above may permit the pipe to attain great length and size before collapsing or caving in.

There is evidence that piping often occurs in medium- to heavy-textured alluvial soil lying immediately above a water table. Pipes have been observed to erode from river banks at a point level with the current river flow, and, as the river channel cuts deeper, there has appeared to be a simultaneous lowering of the base of the pipes. Within the past twenty to sixty years of stream lowering in the Pomerene area, pipes emptying into the San Pedro River have developed high vaulted roofs, but the outlets of the pipes have continued to remain on the same level with the lowering river channel (Fig. 11).

Though the formation of subterranean voids or pockets as a direct result of solution of soluble salts has not been observed in the area under survey it is not uncommon to the semi-arid Southwest. Soluble salts in the subsoil and substratum may be taken into solution by leaching water and moved to a lower horizon. The subsequent voids or pockets formed may, in turn, permit sizeable amounts of soil in upper layers to migrate downward in suspension.

Method of Handling Piping Soils

The consensus among farmers in this area has been that piping can be controlled by the filling in of eroded spots with undecomposed organic matter or a mixture of undecomposed organic matter and soil. This method of treatment may prove effective in eroded areas of most soils, but in a highly-dispersed piping soil the excessive permeability created by the loose undecomposed organic trash would still permit free water plus soil in suspension to find egress through the loose fill. In several areas where this method of control was attempted the soil around the original sinkholes and pipes eroded away, leaving trench-encircled heaps of organic trash.

Some farmers have attempted to control lateral piping by driving wood pilings into the earth at a point below the eroding areas, thus attempting to cut off the escape of the migrating soil. Others have driven sheet-iron plates into the subsoil to cut off the pipes, and still others have poured concrete dams along the lower end of their fields. One farmer near Pomerene dug a trench eight feet deep along the lower end of his field and maintained a vigilant watch to check the formation of new pipes. In all instances, it is obvious that the maintenance cost was high, and that, in many cases, the farmers were not only failing to control the cause of the trouble but were neglecting to apply the most economical or effective remedy.

It has been observed that those farmers who have successfully dealt with piping soils in these areas have learned that pipes,

Figure 12. Outlet of a high vaulted subsurface tunnel. Note that the base of the tunnel has eroded to a point level with the current flow.

sinkholes and earth fissures must first be "dozed out" with a tractor to remove all traces of the voids and tunnels. In some instances, tractors have been known to drop out of sight into these subterranean cavities, but work is not halted until all traces of active pipes and sinkholes have been removed. Afterwards, damp soil is shoved into the "dozed-out" areas and packed down. Compaction of the earth fill may be accomplished by the use of hand-tampers or by frequent passes of the pneumatic tires of the tractor. Uniform compaction of the fill is best obtained if the "dozed-out" areas have graded side slopes.

It has been noted, too, that a later building-up of the humus content of the soil surface is of primary importance in piping control. It not only acts as a deterrent to a too-rapid permeability, but it also binds the surface soil together, increases soil friability and lowers the amount of surface cracking. Farmers in southeastern Arizona are rapidly learning the value of plowing under straw, stubble and other organic trash as a measure in the prevention of piping.

It has been suggested by several farmers that deep-rooted legumes should be limited to not more than a two-year growth to prevent the formation of a too-deep tap root. Shallow rooted legumes have been mentioned as a substitute for alfalfa.

Extreme care in irrigation practices, including waste-water control, is another important factor in the prevention of piping. Farmers of the San Pedro River valley agree that where there is deep moisture penetration, piping may be kept under control. This is a logical conclusion in that if heavier-textured surface and subsoils are kept moist, shrinkage cracks and subsequent piping may be held to a minimum. In all areas, farmers are learning that a more efficient use and control of irrigation waste-water eliminates repeated inundations and subsequent erosion of soils susceptible to piping (Fig. 13). The majority of the farmers have learned that, if it is necessary to run tailwater, care should be taken to spread out the water to prevent its being channeled into piping areas.

Leveling of land to an irrigable grade and removal of channels of water concentration have been found to help alleviate subsurface erosion. If land is so leveled that irrigation water or surface run-off is prevented from being funneled into cracks, holes and burrows, the control or prevention of piping, in many instances, is simplified. If it becomes necessary to impound water on soil that is known to pipe care should be taken to seal off all soil cracks and openings. Evidences of the ability of these soils to hold water under such a practice is shown by the presence of numerous serviceable stock and storage tanks which stand near piping areas.

The majority of the farmers who cultivate land adjacent to the

Figure 13. Piping resulting from the erosive action of enchanneled waste-water. The above pipes have eroded through seventy-five feet of subsoil to a nearby river channel.

high banks of the San Pedro River maintain buffer strips of native vegetation between the cultivated land and the deeply cut river bed. Every precaution is taken with irrigation waste-water and surface run-off to prevent overflows and possible introduction of piping into these areas.

There is no approved practice that will halt cracking resulting from land settling, but care can and should be taken to apply corrective measures to the fissures once they are observed.

An efficient program of rodent control on many farms has minimized and, in some instances, halted piping resulting from animal holes and burrows.

Summary

The subject matter of this report is based upon personal observations made of the erosional behavior of piping soils in the Santa Cruz and San Pedro River basins in southeastern Arizona. In this investigation, primary consideration has been given to factors which have been observed to initiate and accelerate subsurface erosion.

This paper deals specifically with the occurrence and formation of pipes and sinkholes in the Tucson-Nogales and Benson areas of Arizona and, in as brief and simple a way as possible, discusses methods employed by the farmers in these areas to prevent piping or to reclaim land that has already begun to pipe.

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